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Title: NONLINEAR WAVE PREDICTIONS IN CERAMICS

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NONLINEAR WAVE PREDICTIONS IN CERAMICS

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The accurate numerical prediction of nonlinear waves in metals and ceramics is important in the design of many products including aerospace structures, automobile engines and other devices. The material strength and fracture of ceramics must be predicted in order to achieve optimum designs. As part of a project to develop a reliable, robust, design computer program a number of material strength and fracture models have been implemented into the MESA-2D hydrocode and the predictions from the code have been compared to data. MESA-2D is an explicit, finite-difference Eulerian code with hydrodynamics, high explosives, material strength, fracture, and a number of equation of state models.

The interface velocity as a function of time between an alumina target and a lithium floride window, impacted by an alumina disk at velocities between 544 m/s and 2329 m/s, was predicted by using the Steinberg ceramic material strength model [Steinberg, Daniel (1990) Computer Studies of the Dynamic Strength of Ceramics, Lawrence Livermore National Laboratory Report UCRL-ID-106004] and a maximum tensile fracture model. These one-dimensional flyer plate experiments were conducted at Sandia National Laboratories using Coors AD 995 alumina.

INTRODUCTION

The development of an accurate, predictive hydrocode design tool for impacts into brittle materials is important in a number of technical areas including armor and warhead development, space debris protection, enhanced oil recovery, and other areas where advanced ceramic materials are being used. The goal of the present work is to implement material strength and fracture models for brittle materials in the MESA family of codes and to evaluate the models in order to further the effort to produce a design tool.

In previous work (Mandell and Henninger, 1992) two ceramic models were implemented into MESA (Johnson and Holmquist, 1992; Steinberg, 1990) and evaluated against 1 D and 2 D experiments (Kipp and Grady, 1989; Wise and Kipp, 1990). The data from these experiments consisted of VISAR (laser velocity interferometer system) velocity versus time data. The alumina used in those experiments was very porous and nonuniform. The constants for the material models used in the previous work were not obtained for the alumina used in the experiments, which probably accounts for the poor agreement between the data and the predictions reported. In order to determine the cause of those prediction problems, predictions for a better characterized alumina, AD 995, were made in the present work. These predictions are discussed below. For AD 995, alumina constants are available for the Steinberg model, but constants are not available for the Johnson Holmquist model. Therefore the Steinberg model was used in the current work.

Since the Steinberg model includes formulas for the yield stress and the shear modulus, but does not include a fracture component, a maximum principal tensile stress criteria was used to predict fracture. As discussed below, fracture has a small effect in 1 D predictions, but fracture is critical in 2 D impact penetration predictions (Mandell, 1993).

COMPARISON OF PREDICTIONS AND DATA

Figure 1 shows the hydrocode geometrical setup for the flyer plate calculations. In the experiment an alumina flyer plate impacts an alumina target backed by a lithium floride window

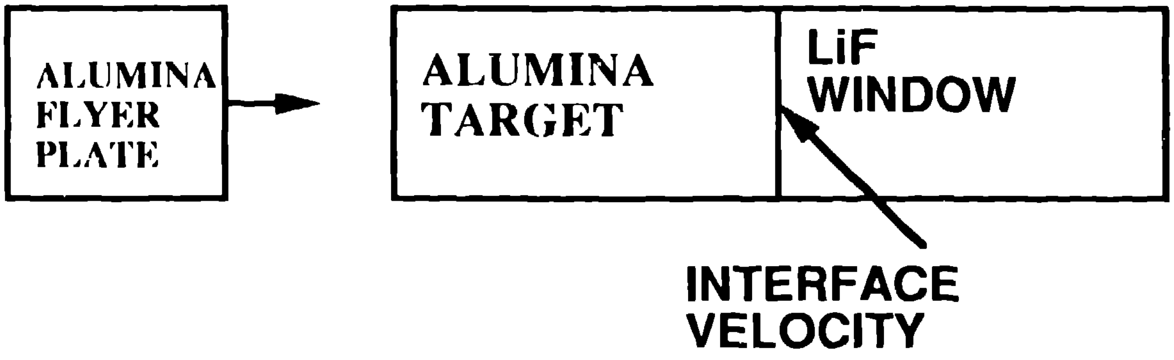

Fig. 1. MESA2D Geometry for the 1-D Flyer Plate Experiments

A VISAR is used to measure the velocity as a function of time at the target window interface. Five experiments at flyer plate velocities from 544 m/s to 2329 m/s were predicted. The results for three representative predictions are shown in Figs. 2-4, and the other predictions are given in a report (Mandell 1993).

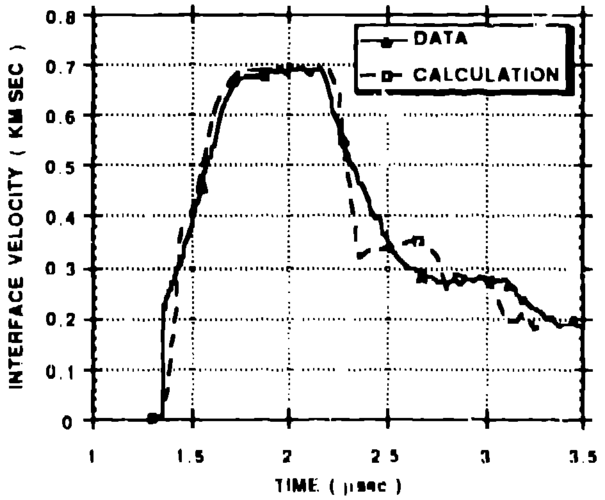

Fig. 2 Experiment CE 57 at 1019 M/S

At the lower velocities the agreement between the predicted velocities and the measured values is good, but the code increasingly overpredicts the peak velocities as the impactor velocity increases. At the maximum velocity (2329 m/s), the prediction is 12.3 percent too high.

Fig. 4 shows a comparison of three predictions and the data for experiment CE 60 in which the flyer plate velocity was 2329 m/s. The prediction with the material strength and fracture options turned off shows that the peak velocity is unaffected by these models. An

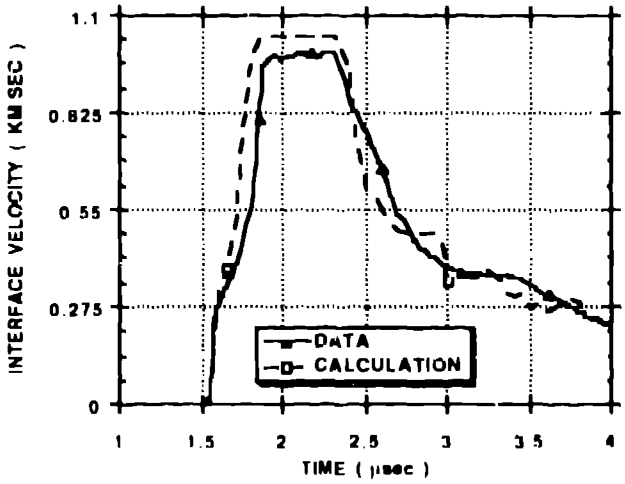

Fig. 3 Experiment CE 58 at 1588 M/S

overprediction can, therefore, only be produced by the equation of state (EOS). By substantially modifying the EOS of the alumina, the correct peak velocity can be calculated. The U_s-U_p EOS was used for the alumina, where U_s is the shock speed and U_p is the particle speed. The equation for the Hugoniot is $U_s = C_0 + S U_p$. The sound speed C_0 and the slope S are found from experiments. The sound speed was changed from 0.771 cm/μs, the nominal value, to 0.550 cm/μs, which is in the direction that would be produced by increased porosity. The hydrocode does not calculate porosity for brittle materials, but this EOS change may indicate that a porosity calculation would produce better agreement between the data and the prediction. The flyer plate velocity was measured to within ± 2.0 percent (Grady, 1993). In order to calculate the measured peak velocity, the flyer plate velocity has to be decreased by approximately 10 percent,

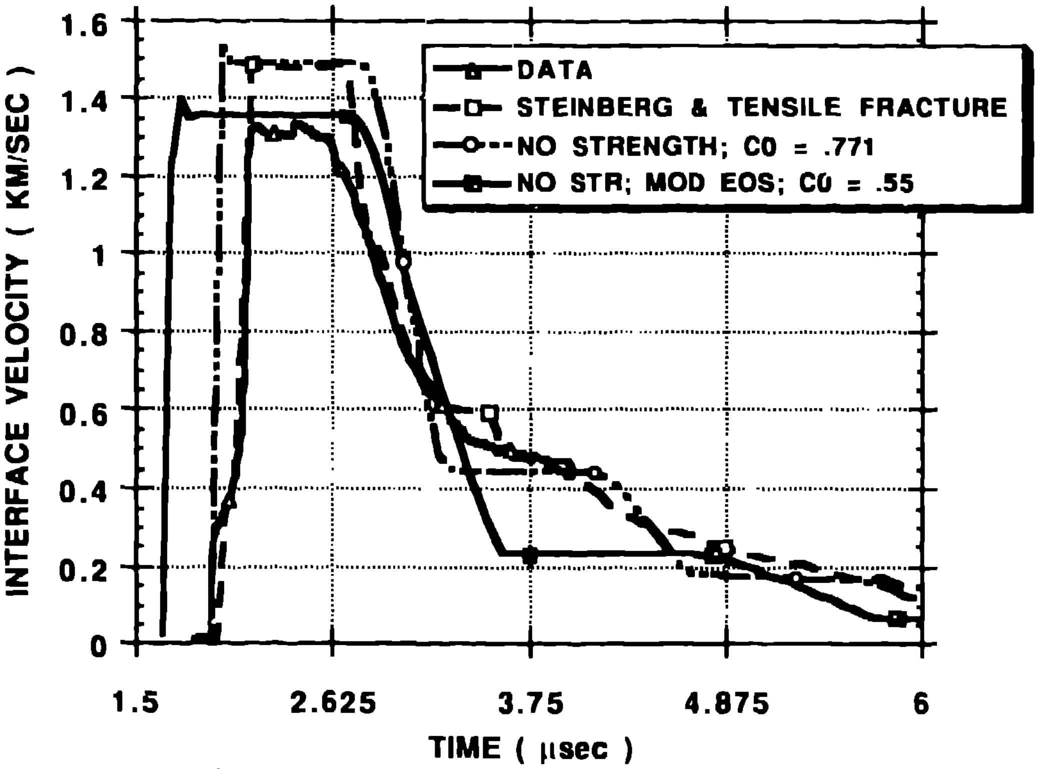

Fig. 4. Experiment CE 60 at 2329 M/S - Effect of Material Strength and Equation of State.

so this uncertainty in the experimental flyer plate velocity does not account for the peak velocity overpredictions. Further work is needed to determine the reasons for this discrepancy.

The effect of the maximum principal tensile stress fracture value was examined for the lowest velocity experiment, CE 56, and for the highest velocity experiment, CE 60. The results for experiment CE 56, which showed the greatest effect due to the variation of the maximum principal tensile stress, σ_{max}, chosen for the fracture criteria, are shown in Fig. 5. Moderate changes in the value of σ_{max} have very little influence on experiment CE 56 results and almost no effect on experiment CE 60 results, Fig. 6. In contrast, in the predictions of Anderson and Morris's 2 D penetration data (Anderson and Morris, 1992), the fracture model was critical (Mandell, 1993). The maximum principal tensile criteria gave very poor results whereas the Johnson Holmquist model predicted the 2 D penetration data to within 11.4 percent. The 2 D experiments used an alumina for which Johnson Holmquist model constants are available.

Data is needed on the yield stress, the shear modulus, and the bulk modulus of fractured ceramic so that models in which time dependent fracture is calculated have the necessary material properties.

The importance of various model features can be missed when simple experiments are predicted by a hydrocode, such as the importance of fracture when calculating the one dimensional flyer plate experiments. Therefore, real design problems involving ceramics need to be calculated in order to assess the models fully.

The development of new brittle material strength models needs to be done in parallel with their application to design problems of interest so that the models work effectively and robustly in hydrocodes.

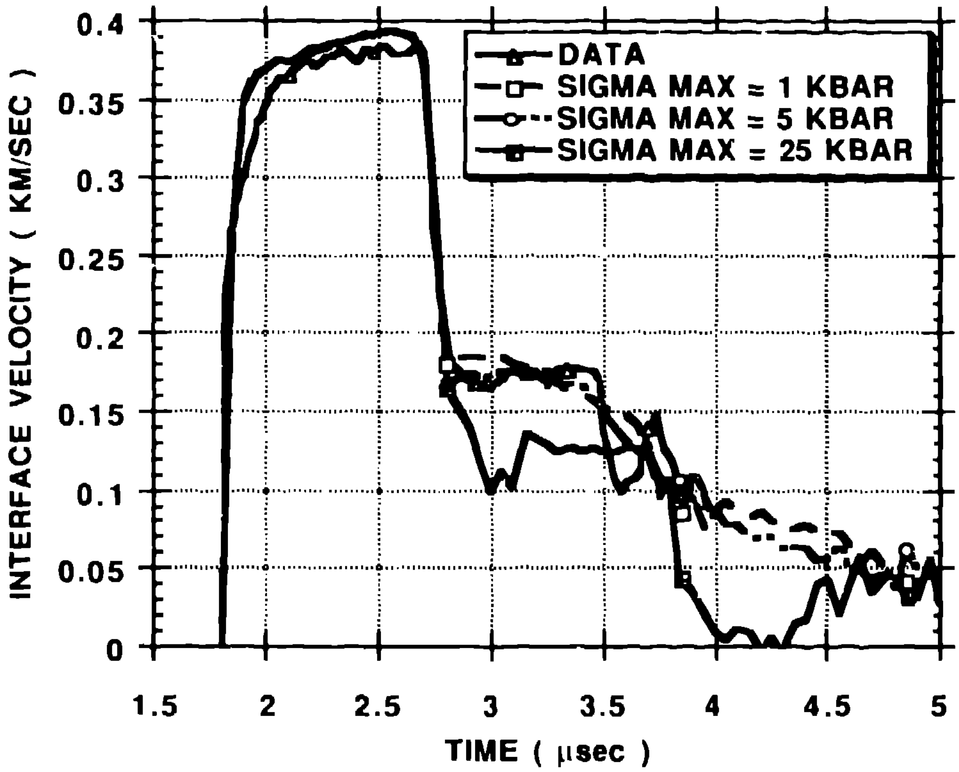

Fig. 5. Experiment CE 56 AT 544 M/S
Effect of the Tensile Fracture Value.

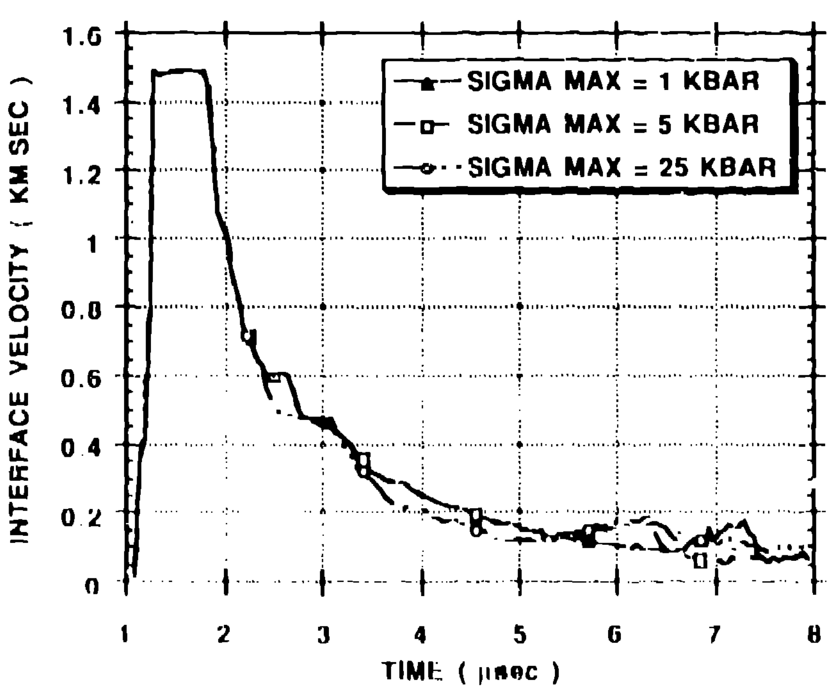

Fig. 6. Experiment CE 60 at 2329 M/S
Effect of the Tensile Fracture Value.

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